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Chapter 5

The origin and the special role of coherent water in living systems

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Abstract: According to quantum electrodynamics (QED) liquid water is a two-phase system in which one of the phases is in a coherent state where all molecules are phase correlated, whereas the other is made up of uncorrelated molecules in a gas-like state. Recent data demonstrate that interfacial water adjacent to hydrophilic surfaces exhibits peculiar anomalous properties, e.g., it is electrically charged and the sign of its charge is the same as the charge of the contiguous hydrophilic surface. It is known as "Exclusion Zone water" (EZ-water) because it excludes solutes. In this paper we show that these properties of interfacial water can be derived from the properties of coherent water. We analyze in the QED frame the dynamics of formation of EZ-water, the origin of its anomalous properties, and its relevance in living systems, where water is almost entirely interfacial being close almost everywhere to some macromolecular backbone or to some surface. We conclude that all the above properties of EZ water are the consequence of the coherent collective oscillations occurring within liquid water and on its boundaries.

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Introduction

Water in living systems has been traditionally considered a solvent in which biochemical reactions occur and which coincides with ordinary water. This vision meets some inconsistencies. We will show in the following that molecules, in particular, water molecules, don't play a chemical role *only* but also a physical one, so that the role of water becomes extremely important when the physical dynamics of molecules is taken into account, suggesting that water properties in living systems differ from those of ordinary "bulk water". In fact, in biological systems chemical reactions cannot occur at random but should follow specific well-defined sequences, where each reaction occurs at a definite site and definite time; in other words chemical reactions should follow strict space-time codes (Del Giudice et al., 1985; 1986; Barbieri, 2002). This point has been stressed a long time ago by such prominent biologists as Albert Szent-Gyorgyi (Szent-Gyorgyi, 1960) and Gerald Edelman (Edelman, 1984), who pointed out to the inconsistency of the observed biological order with a biochemistry governed by a diffusion regime. As emphasized by Schrödinger: "it needs no poetical imagination but only clear and sober scientific reflection to recognize that we are here obviously faced with events whose regular and lawful unfolding is guided by a "mechanism" entirely different from the "probability mechanism" of physics" (Schrödinger, 1944, p.79). A physical agent is needed to organize the traffic and collective interaction of molecules; this is not a speculation but a logical, necessary consequence of the existence of order in biological systems. In our study it emerges as a logical consequence of Quantum Electrodynamics (QED).

In this connection we recall that in electrodynamics two molecules oscillating at frequencies ν_1 and ν_2 respectively, within an extended electromagnetic field (EMF) oscillating at a frequency ν_0, develop a very strong attraction whose range could reach the size of extent of the EMF when the three frequencies ν_0, ν_1, and ν_2 coincide, namely their differences are smaller than the thermal noise kT, which at room temperature is 0.025 eV (Askaryan, 1962; Del Giudice et al., 1986; Beige et al., 2005). Since in living organisms water appears as a medium in which biomolecules are suspended, a self-governing scheme for biochemical reactions emerges should water be able to give rise to an extended EMF.

If water molecules are assumed to be bound by short-range static forces, (Franks, 1972-1982), they may at most oscillate in a random fashion due to thermal excitation. This excludes any possibility of a large scale coherent oscillation which, as we will see below, is of crucial importance for the water molecular dynamics.

In the last decades a different picture has emerged from quantum electrodynamics (QED). This approach has been extensively described by Preparata (Preparata, 1995). Experimental investigation of water close to

hydrophilic surfaces (interfacial water), performed mostly in Gerald Pollack's laboratory, has shown the existence of layers, as thick as some hundreds (up to 500) of microns, of a variety of water organized differently than usual bulk water (Zheng et al, 2006), termed "Exclusion Zone water" (EZ-water). Observed properties of EZ-water imply that it represents an ensemble of molecules correlated in space and time by its own dynamics, different from the one governing the usual bulk water.

Our discussion combines the theoretical QED description of liquid water with the experimental data on interfacial water and discuss its role in living systems, where the extremely developed hydrophilic surfaces, which are made up by biopolymers and supramolecular structures, transform a significant part of biological water into EZ-water.

1. What is coherence?

In 1916 Nernst (Nernst, 1916) proposed that quantum fluctuations of elementary components of a physical system could be tuned together giving rise to a collective, in phase, oscillation so that the many elementary components behave in unison, as a whole, and lose their individuality. The dynamical regime corresponding to this possibility is termed *coherence* and is indeed experimentally observed in superfluid Helium, crystals, magnets, superconductors and other systems where ordered patterns appear. In all these systems, coherence is the macroscopic manifestation of the microscopic dynamics of the elementary constituents provided that some boundary conditions are satisfied, such as the density being above a critical value and the system temperature being below some critical threshold T_C. Notice that T_C does not need to be very low, as it happens in superfluids and superconductors; crystals and magnets exist at room temperature and their critical temperature T_C may have quite high values depending on the specific material they are made of (Blasone et al., 2011) (e.g. the diamond crystal loses its coherence (it melts) at a temperature of about +3545 °C). The energy of the coherent state, namely the one where the system components have a well-defined common phase of oscillation, is lower than the original non-coherent ensemble of components (Fig. 1). This difference of energy is termed *energy gap*.

The existence of the energy gap accounts for the stability of the coherent state (its robustness) against thermal or other external perturbations and prevents the individual components to transform independently of the ensemble. Below T_C, the energy supplied by thermal fluctuations is less than the energy gap and therefore unable to destroy the coherence.
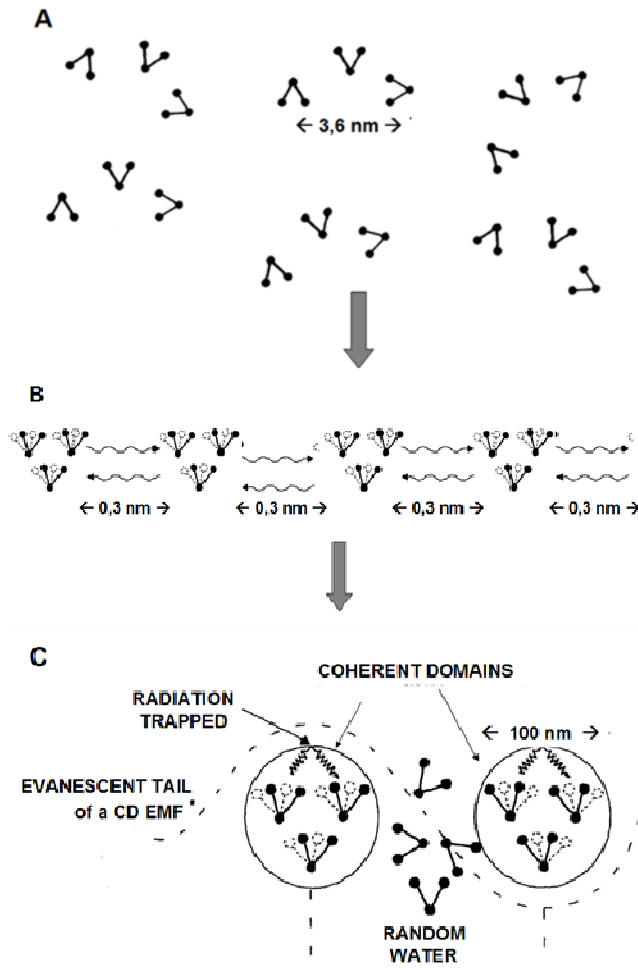
Figure 1. Emergence of coherence. An ensemble of quantum particles, here water, is taken as an example. (A) Water molecules in vapor oscillate independently from each other in a non-coherent way because of long distances between them (density is below the critical density). (B) When vapor condenses into water (temperature decreases below a threshold and density increases above a threshold), water molecules start to oscillate in phase (minimum of energy) – the condition for coherence. (C) Coherently oscillating water molecules get together with associated EMFs in Coherent Domains (CDs) immersed in dense gas-like non-coherent water. The ratio of non-coherent to coherent (CDs) water in liquid water depends upon temperature.

The dynamical regime where coherence is established does not require, in general, the presence of an externally supplied cavity and of a pump (as on the contrary it happens in laser physics).

The electromagnetic fields (EMF) and the electromagnetic potential play a relevant role in the physics of coherent systems. Consider an ensemble of a large number N of quantum particles (e.g. electric charges, dipoles, multipoles). Quantum fluctuations among their inner states, e.g. their lowest energy state and one of their excited states, imply that they emit or absorb EMF radiation (*radiative* EMF). One can show (Preparata, 1995; Arani et al, 1995; Bono et al, 2012; Del Giudice et al, 1988; Del Giudice & Vitiello, 2006; Blasone et al, 2011) that the N particle ensemble gets coupled to the radiative EMF and transits from the non-coherent state to a (lower energy) coherent one, provided that the ensemble is above a density threshold and below a temperature threshold: the particles (the matter field) and their radiative EMF get coupled together in a coherent whole, a common in phase dynamical oscillation, in a way that the self-trapping of the original radiative EMF is generated, which thus cannot be any longer irradiated outwards (Preparata, 1995)). The in phase fluctuations of the EMF field (the gauge field) and of the matter field (the particles) characterize the minimum energy state of the system, namely the quantum vacuum.

Self-trapping involves fields only. Electromagnetic potentials are not trapped. Potentials are coupled to the phase, and can give rise to observable physical consequences also in the absence of fields, provided that some topological singularities are present. This is widely confirmed by experimental observations of so called topologically non-trivial extended objects, such as, e.g., vortices (Blasone et al, 2011), and in the celebrated Bohm-Aharonov effect (Aharonov & Bohm, 1959, 1961), on which we do not comment further for brevity.

As mentioned above, thermal perturbations may destroy coherence. Laboratory observations of superfluids, superconductors and other coherently ordered materials show that at the system boundaries and/or between ordered and non-ordered domains internal to the system, a dynamical equilibrium is reached where component molecules are crossing over continuously between coherence and non-coherence. At any definite value of the temperature T the fraction of molecules belonging in the average to the coherent state is well defined. However it is impossible to tell which molecules belong to which fraction.

When coherence is lost, the trapped EMF is released outwards in many ways. If decoherence occurs slowly the EMF energy can be released as heat (thermal radiation). When on the contrary the process is fast, as it occurs, e.g., in sonoluminescence (Putterman & Weniger, 2000), the em field is observed as a flow of photons. This is presumably the origin of the so called "degradative mitogenetic radiation" discovered by A.G. Gurwitsch (Gur-

witsch & Gurwitsch, 1943) and of the more general phenomenon of "emission of biophotons" discovered by F.A.Popp (Popp, 1979), which are therefore the *debris* of a previous coherent field governing the biological system. Within coherent physical systems, including presumably biological systems, the EM field, being coherent, cannot be conceived as an ensemble of a defined number of photons; it acquires this form only after the disappearance of coherence.

2. The QED picture of aqueous systems

The QED study of liquid water shows (Preparata, 1995, Arani et al, 1995; Bono et al, 2012) that a coherent oscillation of the electron clouds of water molecules occurs. Many physical observables of liquid water have been calculated in QED without any *ad hoc* hypothesis or modelling, such as the critical density, the specific heat, the latent heat of boiling (Arani et al, 1995). We emphasize that coherence of the electron cloud oscillation in water is not a speculation but the result of QED computations applied to liquid water.

In such a coherent dynamics water molecules oscillate between the ground state of their electron cloud and an excited state at 12.06 eV; in the ground state all electrons are tightly bound and the ionization potential is 12.60 eV. In the excited state one electron becomes quasi-free and could be released away either by a quantum tunnelling effect or by a mild external perturbation. Coherence extends over the spatial region of the size of the wavelength of the EM mode of 12.06 eV, namely 0.1 microns (Preparata, 1995) (Fig. 1). Such a region is named the Coherent Domain (CD). The *energy gap* matches the cohesion energy of liquid water, so that this coherent process describes the transition from vapor to liquid. The frequency of the trapped EMF lies in the infrared (IR) region of the spectrum. The oscillation of the electron clouds of water molecules participating in the coherent dynamics pushes one electron per molecule just below the ionization threshold. Therefore CDs become pools of quasi-free electrons. The presence of a large number of quasi-free electrons in the CDs is the first step of the process allowing coherent water to become an electron donor, this process implying the additional dynamics described in the following. We remark that the QED results illustrated above fit completely with known facts such as the availability of electrons supplying the redox chemical reactions involved in cell respiration (Voeikov & Del Giudice, 2009). This availability cannot be explained in the picture where electrons are tightly bound to their parent molecules.

In addition to the above process, another coherent process had been recognized in 1988 (Del Giudice et al, 1988). In this case the coherent oscillation involves the electric dipoles of water molecules, which oscillate between

the molecule ground state and the low-lying rotational states at about 20 cm^{-1} (the cm^{-1} is a unit used by spectroscopists which corresponds to 30 GHz). The dipole coherent oscillation predicts the appearance of an extended fluctuating electric polarization field, which, in the absence of an externally applied electric field, averages to zero. When an external electric field E is present, the polarization field acquires a permanent component parallel to E; the size of the coherence domain relative to this process, measured by the wavelength of the EM mode responsible for the oscillation, reaches some hundreds of microns, depending on the value of E. Coherence of electric dipoles allows us to predict that liquid water close to sources of electric fields, such as polyelectrolytes or hydrophilic surfaces must be strongly polarized, which is well known from experiments (Celaschi & Mascarenhas, 1977). In bulk water – far from surfaces, molecular backbones or other sources of electric fields – rotational coherence is absent. Close to surfaces or other electrically charged bodies, the combination of the above two kinds of coherence produces most of the peculiar landscape of EZ-water, in particular the depth of the EZ layer whose size (hundreds of microns) coincides with the size of the domains of this electric dipole coherence. The complete interpretation of EZ water demands still some additional coherent processes. Ensembles of charged particles can become also coherent. Indeed, ensembles of ions suspended in water have been shown to become coherent producing an energy gap of about 3 eV per ion (Del Giudice et al., 2000). When the binding energy among ions constituting a molecule becomes smaller than the sum of the energy gaps of the components ions, the molecule splits as it occurs in the Arrhenius spontaneous electrolyte dissociation. In the case of "normal" water the binding energy of the pair H^+-OH^- in the individual water molecule is large enough to prevent the split (water dissociation). However, in the coherent state the binding energy of the pair decreases because the electron cloud is made wider by the coherent oscillation. This decrease is still larger when the two kinds of coherence (the electronic one and the dipole one) described above are simultaneously present. Because of this decrease the binding energy becomes quite close to the gain of energy produced by the split, which therefore can occur under small perturbations giving rise to the pH phenomenon. In any case we have a number of quasi-free protons, which mirror the existence of quasi-free electrons and can give rise to a plasma oscillation.

We have seen that in liquid water many coherent processes can occur simultaneously, especially when non-aqueous impurities are present. This is the case of biological water which is a much more complex matter than pure liquid water. The major feature of biological water is that a very essential part of it is contiguous to solid surfaces of hydrophilic polymers and of their supramolecular complexes. Water adjacent to hydrophilic surfaces is highly organized and has a lot of peculiar properties that makes it very different

from bulk water. We describe below some of the properties of this water and point out that its origin and properties cannot be explained unless one considers the coherent property of water that follows from the quantum approach.

3. Major properties of EZ-water

In the last years Gerald Pollack and his associates have shown in a series of experiments that water adjacent to hydrophilic surfaces (interfacial water) is a new allotropic form of water dynamically different from bulk liquid water (Zheng & Pollack, 2003). They found that colloid particles and different solutes are excluded from aqueous zones closely adjoining to hydrophilic surfaces on the order of tens and hundreds of microns. Such water was termed exclusion zone water (EZ-water). EZ-water is different from bulk water not only in its solvent properties; it has higher dynamic viscosity, diminished infrared emissivity, retarded (T2) relaxation time in the NMR excitations, shorter spin-lattice (T1) relaxation time probed by NMR and smaller self-diffusion coefficient than bulk water (Yoo et al, 2011). All these properties imply that EZ-water is much more internally constrained than bulk water. Still, in no case does this water represent ice, it is rather a dynamically ordered entity.

It is known that coherent water expels all the molecules and other particles unable to resonate with it (Preparata, 1995), so that, should we be able to keep water coherent for a time long enough, we would observe the phenomenon of solute exclusion. In normal water this phenomenon is not observed because coherent and non-coherent fractions cross over continuously one into the other producing a seemingly homogeneous time average. Close to hydrophilic surfaces, the coherent fraction of water gets somehow stabilized in time and the phenomenon of solute exclusion becomes observable.

A negatively charged surface is, *e.g.,* a polymer functionalized with sulphonic groups. Low entropy Exclusion Zone water is adjacent to the surface, and it is negatively charged with respect to bulk water. The potential difference decreases with increasing distance from the charged surface. Protons accumulate near the distant part of EZ-water; the farther the distance from the edge of EZ-water, the lower their concentration.

One of the most mysterious properties of EZ-water is that of being electrically charged with respect to bulk water. EZ-water near a surface bearing a net negative charge gets negatively charged, too, and it gets positively charged near a surface with a net positive charge (Zheng et al, 2009). When negatively charged water is formed close to a negatively charged surface
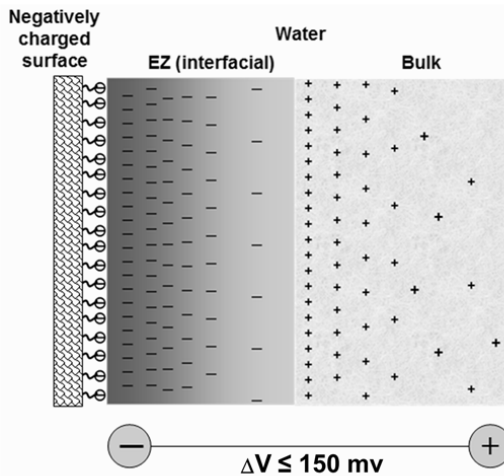
Figure 2. Schematic composition of an aqueous system near a negatively charged surface.

a zone enriched with positive charges represented by protons or hydronium ions is located beyond the EZ-water layer (Fig. 2). These protons originate from EZ-water adjacent to the negatively charged surface but they are attracted by bulk water (Chai et al, 2009). On the contrary hydroxyl ions are located close to positively charged water formed close to positively charged surfaces (Nagornyak et al, 2009). It is an intriguing feature that no opposite electric charges have been found so far between the two layers of like charges – a solid surface and an adjacent EZ-water layer. Experiments show that the potential difference between charged water and bulk water may reach more than 150 mV. Moreover, the higher the density of fixed charges on the solid surface, the deepest the thickness of charged EZ-water (Zheng et al, 2009). Notice also that though the viscosity of EZ water is higher than the viscosity of bulk water it is still a liquid. So its elements are not strongly bound to each other, and though they are likely charged they do not repel each other and do not repel the surface carrying like charges, rather they durably adhere to it. This experimental finding contradicts the electrostatic attraction/repulsion law. In the following we suggest that the "like likes like" mechanism may allow resolving this paradox.

4. What is the origin of EZ-water?

Charged surfaces present usually a polymeric or crystalline backbone to which chemical residues bearing easily ionizable groups are covalently

bound. The charge of these groups can be either positive or negative, or both. Typical examples of such surfaces are ion-exchange resins, nucleic acids where the negative charges are residues of phosphoric acid, proteins, bearing both positive and negative amino acid residues, many species of polysaccharides, and ensembles made up of different combinations of these substances. It is interesting to note that most, though not all, biopolymers carry net negative charges, sometimes with a very high negative charge density.

Like charges are covalently fixed to a matrix and since each charged residue is surrounded by other charges they all vibrate. Their collective vibration tends to become coherent in order to reduce the total energy of the system. As oscillating charges become the source of an electromagnetic field, a charged surface becomes an antenna emitting oscillatory EMF with a certain degree of coherence in the surrounding space. Vibration patterns of charges depend on the intrinsic and induced vibrations of the polymeric matrix on which charged groups are fixed. This allows for a multi-mode lasing of the surface (Fig. 3).

Since a charged surface is hydrophilic, when immersed into water it becomes hydrated. According to hydrogen bond models of water, in its interaction with hydrophilic surfaces the thickness of hydration water does not exceed 1-2 layers in contrast with experimental observations which show thicknesses of tens and hundreds of microns (Zheng & Pollack, 2003). Liquid water can host simultaneously several coherent oscillatory modes. These modes include electron cloud oscillation of molecules in tune with self-trapped EMF, oscillation of the electric dipoles of water molecules and oscillation of the plasmas of both negative electrical charges (quasi-free electrons) and positive electric charges (quasi-free protons).

If the coherent EMF of a charged surface contiguous to water gets into a resonance with the coherent CD, the latter will be attracted by the charged surface. As an oscillating CD is approaching the oscillating charged surface, the amplitude of the oscillations of a CD is increasing since the intensity of the field increases with the square of the number of the components (Preparata, 1995). Inasmuch, as in EZ-water, there is coherence between the boundary regions of water and the wall, there will be an additional decrease of the binding energy of the pair H^+-OH^- in the water molecule. Consequently the gain of energy produced by the split of the water molecules into ions joining coherent ensembles becomes competitive with the binding energy of the pair H^+-OH^- making possible the separation of H^+ and OH^-.

When the surface is negatively charged, and the EMF produced by it resonates with the EMF produced by oscillations of the quasi-free electrons of a CD, proton plasma cannot oscillate with the same frequency of the electron plasma because of the difference of mass between protons and electrons and therefore the positive and negative plasmas repel each other. When this

happens, CD water converts into EZ-water. If the surface carries fixed nega-tive charges CD water converts into negatively charged EZ-water. The pic-ture of a negative body of water surrounded by protons then emerges (Fig. 2).

The degree of coherence of oscillations of the non-compensated negative plasma of EZ-water attached to quasi-polymeric aqueous matrix is highest for the part of EZ-water closest to the oscillating charged surface. According-ly, the negative charge density of EZ-water decreases with the increase of its distance from the charged surface. Overall charge density (electrical poten-tial) of EZ-water and its thickness depend upon the charge density of fixed charges of the adjacent surface. This scenario explains why a *negatively* charged surface is coated with *negatively* charged water: an oscillatory EMF generated by the surface resonates with the oscillatory EMF of electron plasma CD. The resonance overcomes electrostatic repulsion of like charges since charges oscillating in unison keep together: like likes like (Fig. 3).

In the case of positively charged surfaces immersed in water (for exam-ple, a polymer to which tertiary amines are covalently bound) oscillating species are protons (nuclei). The mass of a proton is about 2000-fold larger than that of an electron, so the frequency range of positive charge oscilla-tions should lie in a range very far from the range of electron (negative charge) oscillations. This coherent EMF will attract the nearby CDs due to the resonance with quasi-free proton plasma of CDs.
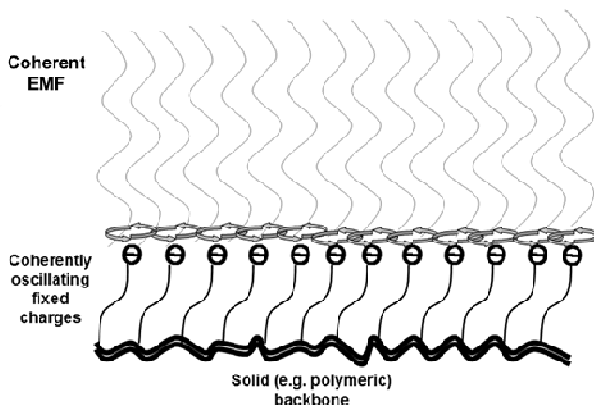
Figure 3. Like charges are covalently fixed to a matrix and as each charged residue is surrounded by other charges they all vibrate. Under certain conditions (see the text) the vibrations become coherent, and the charged surface becomes the source of the coherent EMF.

When CDs approach the surface generating the EMF due to oscillations of fixed positive charges, quasi-free electrons are ejected from coherently oscillating water (probably attached to OH⁻ ions) and an oscillating lattice of positively charged quasi-polymeric water stays attached to the vibrating surface. In conclusion, the above discussion suggests that the presence of CDs in liquid water, predicted by QED, is the necessary and sufficient condition for the emergence of EZ-water adjacent to surfaces carrying multiple fixed charges. Such an origin of EZ-water agrees with all its experimentally determined properties. For example, the higher viscosity of EZ-water than the one of bulk water suggests that the coherent fraction in EZ-water is larger than the coherent fraction in bulk water. Indeed, coherent water is more viscous than non-coherent water since in coherent water one cannot perturb one molecule without perturbing the others. Most important, it explains why EZ-water forming near a charged surface should have the same sign of charge as the one of the surface.

5. Consequences for the living state

The mere existence of EZ water is a demonstration of the realization of the principle "like likes like" based on the mechanism alternative to that suggested by Feynman implying the involvement of intermediate unlike charges (Feynman et al., 1963). This does not rule out that under certain circumstances Feynman's mechanism advocated by N. Ise (2010) and G.H. Pollack (Nagornyak et al., 2009) may also operate. Here the interaction of different entities is fundamentally based on their ability to possess a coherent dynamics. Their "likeness" and therefore their ability to "like each other" depend here on their ability to resonate with each other. In such a case "like likes like" is equivalent to the so called "resonance attraction" (Fröhlich, 1970; Preparata, 1995).

We think that the principle "like likes like" based on coherent dynamics operates in many important manifestations of biological activity. For example, it has been established that all cells of multicellular organisms have negatively charged surfaces as long as they live within their natural environments (Mehrishi & Bauer, 2002). Their negative charge is in part provided by sialic acids residues of glycoproteins covering the external surface of cell membranes of all eukariotic cells. Negative charges of cells do not interfere with their ability to attach to each other building tissues and organs. Currently this attraction of like charged cells is explained by their gluing together with special adhesive proteins, "calcium bridges", etc. (Gumbiner, 1996). However, there is a good example of negatively charged cells sticking together where the participation of intermediate "unlikes" including molecular glue can be ruled out (Voeikov, 1998). This is the phenomenon of rouleaux formation from erythrocytes in normal blood of hu-

mans (Fig. 4) and many animals. One can observe in taken out blood that erythrocytes which are discoids of diameter about 8 microns array themselves face to face integrating into formation looking under the microscope as stalks of coins (rouleaux).

Erythrocytes are not mobile cells, so that the motion to be considered is a slow Brownian movement. Yet, Canadian hematologist S. Rowlands noticed that when two erythrocytes approach each other over a distance of about three cell radii they begin to move towards each other at a rate several times higher than in the Brownian case (Rowlands et al, 1981). This super long-range interaction between living cells is surprising from the conventional point of view on the nature of biological interactions. First, all erythrocytes are negatively charged, so they should repel rather than attract. On the other hand, if to reduce artificially charge density on their surfaces, erythrocytes do not attract and do not form rouleaux. Second, for super long-range interaction between erythrocytes certain polymeric molecules should be added to the medium: fibrinogen, polyvinylpyrrolidone, poly(ethylene oxide), dextran. These molecules are chemically very different. What unites them, so it is their high hydrophilicity, high molecular weight and fibrous structure. Rowlands states that super long-range interaction between erythrocytes cannot be explained by purely chemical forces, and suggested that human erythrocytes behaved in accordance with the major postulates of Herbert Fröhlich theory of coherent excitation in cells (Fröhlich, 1968, 1970).
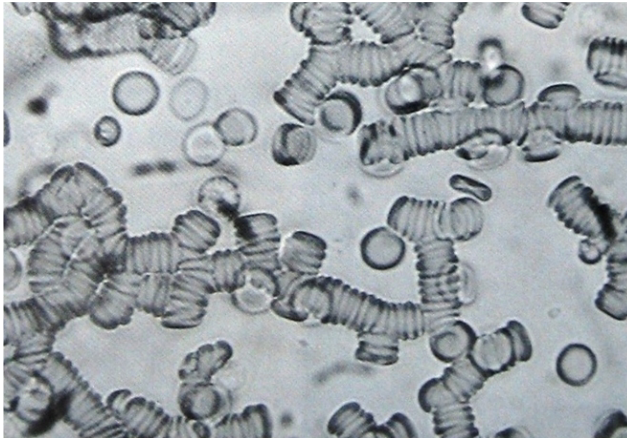
Figure 4. Rouleaux formation from erythrocytes in normal human blood (courtesy from S. Rowlands).

He proposed that "perhaps the property of macromolecule which mediates the transmission of the Frohlich interaction is the molecule's ability to polarize the surrounding water into oriented, ordered multilayers, along which Frohlich polar waves could be transmitted." (Rowlands, 1988). Significance of purely chemical forces after erythrocytes had associated into rouleaux is undermined also by the observation that cells do not stick to each other chemically – the closest distance between neighboring cells is of the order of 1 micron, – several orders of magnitude more than any chemical bond may provide.

Chemical models cannot explain fractional separation of erythrocytes of different species in their mixed suspensions in polyvinylpyrrolidone 360 kDa solutions. For example, in the mixture of human, cat, dog, mice, rat, rabbit, and guinea pig erythrocytes they tended to aggregate into rouleaux significantly enriched with cells of one particular species. Only rat and mice erythrocytes did not distinguish each other probably because these two species are close relatives (Forsdyke D.R., Ford P.M., 1983) (Sewchand L., Canham P.B., 1976.). On the other hand, long-distance interactions based on vibrations of interacting entities should be highly specific, as they should depend on frequencies or phases of the vibrations. Such discrimination is a good illustration of the principle "like likes like" following from the resonance attraction of emitters of EMF with similar patterns.

Specific interaction of erythrocytes may be one of many examples of specific interactions of like charged cells. Rowlands suggests that very fast interaction of platelets in the case of their stimulation *in vitro* may also be explained by Frohlich interaction (Rowlands, 1988).

We could consider this red cells attraction as a manifestation of the general principle of Resonance Attraction, *like likes like*. The coupling of coherent systems, such as living organisms, with electromagnetic potentials allows long-range correlations among coherent systems very far away from each other. This provides for the realization of continuous and practically immediate interactions both within individual living systems and between them.

Conclusion

In this chapter we have presented the coherent dynamical mechanisms implied by QED in water and shown how they open new horizons in biology (and not only in biology). The problem of the interconnectedness of the parts of an organism, the synchronization of their workings, the self-governance of biochemical processes, whose explanation is lacking in the biochemistry frame based solely on the random kinetics of molecular reactions, finds a natural understanding in our approach. The successful estimate of thermodynamic variables (specific heats, latent heats, entropy) of liquid water, as

shown in (Arani et al. 1995), opens a promising pathway for the future. A special role appears to be played by the interaction of different entities based on their ability to possess coherent dynamics allowing them to resonate with each other. Then their "likeness" turns out in their ability to "like each other". This is similar (although different in several dynamical aspects and details) to the so called "resonance attraction" (Fröhlich, 1970; Preparata, 1995).

The actual description of biological dynamics in quantitative terms appears to us the next task for our research. Much work needs still to be done in such a direction. However, the present stage of our analysis already leads us to the conclusion that quantum physics, as formally expressed in rigorous terms by QED, plays a crucial role in living matter, so that we can only agree with Schrödinger warning that the "regularities only in the average" (Schrödinger, 1944, p.78) emerging from the "statistical mechanisms" are not enough to explain the "enigmatic biological stability" (ibidem p.47). Pretending to explain the biological functional stability in terms of the regularities of statistical origin would be the "classical physicist's expectation" that "far from being trivial, is wrong" (ibidem p.19).

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